gratification of members of the Society, who may desire to know the views of Mr. Chevalier, in regard to the submarine railroad, but find it less irksome to read or listen to them in their mother tongue than in the French.

I avail myself of this opportunity to express my regret that though I have been for a much longer period than my friend Mr. Chevalier, a member of the Society, I have so far written nothing that seemed to me worthy of presentation and of preservation in their records. I am not, however, the less sensible on that account, of the compliment paid me in 1833, when I was elected one of its members.

Respectfully yours,
Moncure Robinson."

Railway under the English Channel. Address of the President, M. Michael Chevalier. Translated by Mr. J. P. Keating, of Philadelphia.

(*Read before the American Philosophical Society, Jan.* 4, 1878.)

Gentlemen: We have deferred until to-day calling you to a general meeting from our desire to render ourselves competent to furnish you with information requisite for the solution of a problem traced out for us in our laws themselves, and which may be this way stated.

Is a submarine railway between France and England practicable without encountering extraordinary difficulties involving immense expenditure?

We desired that the studies to which we have applied ourselves ever since the passage of the act allotting the work to us, should be pushed so far as to enable us in this meeting to give you an idea of the nature and character of the material to be traversed in order to effect the subterranean passage from one shore of the Channel to the other.

It was our duty, moreover, to examine if its stratification was continuous, without presenting fissures or crevices in any appreciable number, or in any menacing proportions, whereby the sea water could penetrate into the works. It was no less interesting to know whether the bed of the intended tunnel was in its composition sufficiently impermeable to guarantee us from any irruption of the great masses of water which are alike our greatest obstacle and our greatest danger.

The work of the year 1876 has been devoted, like that of 1875, to the most minute explorations, both of the surrounding region of country, and of the bed of the Channel itself. These explorations, carried on conformably to the most approved methods, and with every care which science could suggest, have afforded a mass of results which it was necessary, in order to render them available, to group together, and mark out distinctly in sundry plans and charts. These plans, containing all that is essential to the subject matter, have been distributed among you. You have also received reports, to the number of four, in which are set forth the different methods of exploration that have been pursued. In these reports the conclusions derived from the studies are strictly deduced, and you are thus enabled to judge whether the conclusions are satisfactory.

The work of exploration during the year 1876 was much more extensive than that of 1875, and consisted as follows :

First, In the study of the coasts bordering the sea, both in France and in England, and upon which each stratum of the material which constitutes them is easily distinguishable. This study of the coast naturally involved the geological examination of a zone more or less extended of the shore itself.

Secondly, In a study of the bottom of the Channel so thorough as to enable us to draw a geological chart almost as exact as if the water had retired and its bed were left perfectly dry. This study was pursued by means of multiplied soundings in the sea, each one of which is marked upon the large map annexed to the reports which you have before you. It was proposed to conduct these operations in such a manner that the instrument at each sounding, beside indicating the depth of the water, should bring to the surface a sample of the rock forming the bottom of the sea. All these depths obtained, varying with the tide, have been modified by calculation so as to be reckoned with reference to a uniform level.

Finally, We have constructed on the shore at Sangatte, a shaft which has been sunk to the depth of 130 metres ; that is to say about twenty metres below the well-known clay subsoil which plays an important part in the geology of this region. Upon this clay lies the whole of the stratum composing what geologists call the cretaceous formation, and which interests us particularly. Being impermeable, this bed of clay secures the lower layers of chalk from any uprising of the waters which are to be found on a still lower level. It is designated in the reports by the English name *Gault.*

Of the three operations just enumerated, which have all been brought to a successful termination, the second, to wit, the study of the Channel with the design not only of making a hydrographical examination, but of drawing a geological chart of the bed of the sea, was the most delicate and the most complex.

We do not hesitate to assure you, gentlemen, that this portion of the work of 1876 has been accomplished in a very superior manner. We do not believe that a work of hydrography and geology combined has ever been executed, carrying with it such certainty of result. These are merits which the authors of the reports, who were also the authors of the studies pursued, have not in any way sought to bring to notice, but to which we regard it our duty to call your attention.

These divers explorations were organized and directed by the delegated member, Mr. Lavalley, who was enabled upon this occasion to show to what extent he is familiar with all the problems, however great or small, which may present themselves in public works. It is to him particularly that we owe the definite shape of the instruments designed for the deep sea soundings, which have proved so efficacious. To him also are we indebted for the ingenious arrangements that enabled us in the season of 1876 to accomplish with perfect exactness and great rapidity the extraordinary number of soundings which we deemed indispensible in order to render ourselves

sufficiently acquainted with the geology and hydrography of the Channel. The co-laborers of Mr. Lavalley, in 1876, were Mr. Larousse, late hydrographical engineer of the National Marine Corps, and Messrs. Potier and DeLapparent, engineers in the National Corps of Mines. All three by their zeal, their intelligence, and their devotion to a difficult task the national importance of which they fully appreciated, have entitled themselves to the consideration of the learned world, and to your gratitude.

We propose to give you in some detail the principal results of the three classes of operations above mentioned, and to this end it is only necessary to sum up the reports which have been addressed to you. These reports, let me add, are eminently worthy of your attention, and if you will read them in extenso you cannot but approve of them.

I. *The study of the two coasts.* The study of the shores of the Channel proves that the geological formation is very much the same throughout that part which particularly concerns us, comprising the chalk formation. The same layers are found on the two coasts, of the same character, and what is remarkable, having the same thickness. Hence, the presumption, corroborated by other circumstances, that formerly in a prehistoric age, instead of an arm of the sea separating the two shores, there existed a continuous surface of ground, more or less undulated, between the points where since have arisen the towns of Calais and Boulogne on the one side, and Folkestone and Dover on the other. The Channel, in such a hypothesis, would be due to the continual erosion of a soil of little consistency, as is usually the case with the chalk formation, this soil having yielded by degrees to the shocks of the waves of the Northern Ocean ever violently agitated during the stormy season. From this circumstance we derive the hope that the strata to be met with beneath the sea, and through which the tunnel would pass would be as a general thing continuous, and present, if any thing, deflections merely, to which the track of the subterranean railway might conform without much inconvenience.

This hope is substantiated by the fact that on both sides of the Channel the layers of clay forced from the horizontal position in which they must originally have lain, have not been very much displaced. Throughout the greater extent of the Channel on the French side it is a seventh merely, a fact which would appear to indicate that the subterranean commotions which caused the deviations in the layers from the horizontal plane were not of much moment.

II. *Geological chart of the bed of the Channel.* This portion of the studies pursued is worthy of increased attention. At first sight it seemed an insoluble problem, for in almost every region of the earth the bottom of the sea consists of sand and gravel, covering to a great or even remarkable depth the massive rocks that cling to the solid body of the planet. In the Channel of the Straits of Calais, however, runs a current at the rate of about two or three knots an hour, which sweeps away the sand and gravel as it is deposited, and does it the more effectually, from the circumstance of its being quite narrow, and of a depth of not more than 30, 40, or 50 (53

at most) meters. The rock being thus laid bare throughout a large portion of the Channel, it is easy by multiplying the soundings to reach it frequently with the lead. Then by attaching to the lead a steel tube, sharpened at its end, we have the means of bringing to light every time the lead falls, a small cylinder of the material cut out of it. Success is the more assured if the bottom from which the cylinder is to be extracted, be of a comparatively soft substance, as is in fact the case with the different layers of the cretaceous formation.

This state of things and these circumstances, so favorable to our enterprise, had been already revealed by the experiments of 1875, when, notwithstanding the rudely constructed apparatus, and the small and inconvenient steamboat, 1523 soundings had been made, 753 of which had brought to the surface samples of the material beneath. In 1876, sufficient time having elapsed to enable the mode of operation, and the preparations incident thereto, to be brought to the greatest possible perfection, and when a steamboat was provided, offering all the desirable conveniences, 6,148 soundings were made, 2,500 of which furnished little cylinders cut from the bottom. This makes in all, for the two years, 7,671 soundings, and 3,267 samples, of which some however had no scientific value.

In the same lapse of time the operations were twice as many in 1876 as in 1875. The little cylinders thus extracted from the bottom of the Channel, the character of which was perfectly determined by means of a geodesical examination made at the time by Mr. Larousse, were each labeled and enclosed in a vial. They were afterwards examined by the practised eye of our geological engineers, Messrs. Potier and DeLapparent, who, not content with the mere evidence of the senses, frequently had recourse to the precise indications of chemical analysis. They were thus enabled in the majority of instances to ascertain to what special layer of the cretaceous formation the samples belonged, and in this way the geological chart was traced out step by step.

From the very outset we had felt convinced that the success of a submarine railway depended absolutely upon the tunnels' being placed in the chalk formation. In this particular we were in full accord with the English engineers, who, like ourselves, were occupied with the idea of a junction of France and England by means of a submarine railway, and who had even preceded us in their explorations, carried on upon the same system as ours on both sides of the Channel. Outside the cretaceous formation we would find a species of rock either very permeable to water, such as the green free stone, or of great relative hardness.

Chalk has the advantage of being easily perforated; but this cretaceous formation is in this respect by no means equally satisfactory throughout. There is a marked difference between the upper and lower layers. The upper layers, consisting chiefly of a white chalk similar to that worked at Meudon, near Paris, contain more or less water. The lower layers present qualities much more satisfactory to the engineer, whether he have to cross or to remain in them. We have had occasion to note this difference fre-

quently in France, where the working of the most productive mines of the North and of the Straits of Calais has obliged us to sink numerous shafts through the cretaceous formation. The result of a long experience acquired by the coal miners is that the upper layers contain what are called the *niveaux*, subterranean sheets of water, the draining of which is very expensive. The miners, in sinking the shafts, consider their difficulty at an end when once they have reached the lower layers known among them as *dièves*, elsewhere called *Rouen chalk*. In the greater number of instances, these layers have been found to contain very little water, and may therefore be considered practically impermeable.

It happens at times that among these same layers some that are on a higher level are crossed by fissures through which part of the water contained in the upper beds finds its way. These waters, as they descend, meeting the lower and more compact layers of Rouen Chalk, can penetrate no further, and accordingly gush forth into the open air wherever they find an issue. This it is which gives rise on the French coast to the sources of the Cheu d'Escalles, and in England to those of the Lydden Spouts. But the volume of water of this description, which would be found in excavating the tunnel, would be such as could easily be drained by pumps, thanks to the great power which our modern exhausting machines have acquired; and no alarm need be felt on that account.

It being, therefore, evidently to our interest to place the submarine railway as much as possible in the *dièves* or Rouen Chalk, our engineers then applied themselves to the task of computing the space which these layers occupy in that part of the submarine rock which is accessible to us; as also the degree of regularity which they present.

The result of their labors affords good ground for the belief that throughout the whole width of the channel, except in the neighborhood of the two shores, the Rouen Chalk, or lower stratum of the cretaceous formation, is of remarkable regularity, so much so, indeed, that it would be possible to lay the submarine railway almost in a straight line through it, and at a very ordinary depth. At a short distance from the French coast, where the Quenoc rocks are to be seen, and also in proximity to the English shore, on the reef of Varne, the upheavals of the earth are found by our engineers to have caused a deflection in the layers, but without severing them.

It does not appear that there exists elsewhere throughout the whole width of the channel, at least in the part which concerns us, a single break which might be considered an essential obstacle. Indeed, the study of the layers comprising the Rouen Chalk even suggests the practicability of so constructing the tunnel as to enable us to enter this particular formation in France, and to reach the open air in England without having ever quitted it.

The only objections which might be brought to bear against this idea with regard to the whole length of the line, comprising the approaches from the mainland to the sea, would be such as might be drawn, for ex-

ample, from the position of certain spots considered more available for a connection with the railways coming the one from Paris and the other from London. Reasons such as these might, indeed, have some weight.

But apart from considerations of this character, it would be to our advantage, if only on principles of economy, to retain the roadbed wholly within the Rouen Chalk from the place where it descends into the earth in France, to where it emerges into the open air in England.

One circumstance of great importance to us is that the total thickness of the Rouen Chalk is in the neighborhood of sixty metres. As our tunnel would not require more than ten metres for its construction, this would give us ample room to conform to any of those deviations from a straight line in the course of the strata which are more or less common in the interior of the earth, especially since in the present instance, as we have seen, these deviations are of no great consequence. If perchance in order to preserve the previously determined level, we were forced to abandon the shelter of this formation, it would only be for short intervals, and the difficulty would be by no means insurmountable.

III. *The Shaft at Sangatte.* This shaft had for its object to prove the water bearing character, on the one hand, and the relative dryness, on the other, of the different layers of this cretaceous formation. A very simple means was made use of in measuring the quantity of water which the different layers furnished. You will find the account of it in the special report upon this subject. The result was that as soon as the Rouen Chalk was reached the quantity found was exceedingly small.

The present advanced stage of our studies enables us to fix the position of the shaft designed for the removal of the material extracted during the work of excavation, and to mark out the direction of the gallery which will conduct the leakage waters to the shaft. The first thing, then, to be attended to would be the sinking of the shaft, followed by the excavation of the gallery. This latter would be placed in the same stratum with the tunnel, and excavated to the distance of about two kilometers, would serve the purpose of a supplementary reconnaissance of the route to be taken by our enterprise. You are aware that on the part of England explorations have been made even prior to our own, having the same object in view. They were under the supervision of Sir John Hawkshaw, a distinguished engineer, with whom we have entered into relations. From the very beginning he most obligingly made known to us not only the results of his operations, but the mode, as well, by which he had effected them, and gave us, at the same time, models of the instruments he made use of. Our intercourse with him has been of great service to us. We have just transmitted to him the results of our labors during the year 1876, and Mr. Lavalley, the delegate, has repaired to London to confer with him with regard to the definite direction of the tunnel.

These conferences which have brought to light much valuable information from both sides, and have evinced, likewise, that perfect spirit of accord so much to be desired in similar undertakings, will shortly re-open

With the well-known character of Sir John Hawkshaw and the good will which we shall bring to every discussion, well knowing that in this manner we can best fulfill your wishes, the coming conferences cannot fail of excellent results.

We have also to confer with the Railroad Company of the North with regard to the point where our line should join theirs, the decision, of course, to be subject to the approval of the general government.

We continue to have nothing but praise from the administration. They have never ceased to encourage our enterprise. We have just received from them a despatch intimating the Minister's desire to see our works in active operation as soon as possible.

Mr. Fernand Raoul-Duval, the member of the sub-committee who has special charge of the accounts, will make our financial condition known to you. It is very satisfactory. He will also submit for your inspection and approbation a statement of the expenses incurred during 1876.

Since our last meeting, Mr. Cézanne, engineer of bridges and highways, who was a member of the subcommittee, has been removed by premature death from his family, his friends and our Association, so greatly indebted to him for his very many services.

Mr. Talabot having determined from the necessity of increased care of his health to send in his resignation as member of the permanent committee, we have expressed to him our deep regret on being deprived of the co-operation of one so eminent.

On motion of Mr. S. W. Roberts, the thanks of the Society were tendered to Mr. Chevalier, and the MSS. as translated referred to the Secretaries.

The death of Dr. Jared P. Kirtland, Dec. 10, 1877, aged 84, was announced by the Secretary.

Prof. Frazer presented a communication on the cranial planes in a model bust, prepared by Mr. Edward A. Spring, of Perth Amboy, based on a study of the Venus of Milo. The planes belong to the triclinic system.

Prof. Frazer reported the results of an experiment intended to illustrate his views of the formation of limonites.

Mr. Lesley was nominated for Librarian.

Mr. J. S. Price offered the following resolution which was seconded and adopted :

Resolved, That the Treasurer, J. Sergeant Price, be authorized to receive from and receipt to the City of Philadelphia, for the sum of one thousand

dollars ($1000), being the amount of City Loan belonging to the Society, falling due January 1, 1878.

Resolved, That the Treasurer be authorized to invest the proceeds of said loan under the direction of the Committee on Finance.

And the meeting was adjourned.

Stated Meeting, Jan. 18, 1878.

Present, 15 members.

Vice-President, Mr. E. K. Price, in the Chair.

Dr. T. B. Reid, a lately elected member, was introduced to the presiding officer and took his seat.

A letter of envoy was received from the Royal Observatory, Greenwich, London, S. E., Dec. 27, 1877.

A letter requesting the continuance of exchanges and the completion of a set of Transactions A. P. S. was received from the Linnean Society of Bordeaux, dated Dec. 30, 1877.

Donations for the Library were received from the Ed. Revue Politique; M. Melsens; the R. Belgian Academy; Ed. Nature; Leeds Phil. and Lit. Society; Canadian Naturalist; Cornell University; Philadelphia Academy of Natural Sciences; Pharmaceutical Association; Franklin Institute; Penn Monthly; Medical News; American Journal Medical Sciences; Prof. E. D. Cope; Mr. Henry Philips, Jr.; Mr. Lorin Blodget; Ed. Robinson's Epitome of Literature; Bureau of Education and Engineer Department, Washington; Ed. Western Inventor, Cincinnati; and Ministerio de Fomento, Mexico.

The death of Benjamin Hallowell, of Sandy Springs, Md., and also

The death of Thos. F. Betton, of Germantown, was reported on the occasion of the stated annual reading of the list of the surviving members of the Society.